“ETI-Z Series” Centrifugal Chiller Applied Low GWP Refrigerant to Contribute to the Prevention of Global Warming

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In recent years, Mitsubishi Heavy Industries, Ltd. (MHI) has contributed to the prevention of global warming by improving the performance of centrifugal chillers. In addition, centrifugal chillers adopting HFO-1233zd(E), which features the global warming potential equal to carbon dioxide, were developed and launched as the ETI-Z series in September 2015 to help prevent global warming directly caused by refrigerant emission. HFO-1233zd(E) has a volume of refrigerant gas about five times as large as that of the conventionally used refrigerant HFC-134a, but the newly-developed centrifugal chillers were designed with a compact size equivalent to the conventional product using HFC134a. In addition, high performance was achieved with a 3% increase in rated performance.

1. Introduction

For centrifugal chillers, which are refrigeration and air conditioning equipment, CFC refrigerants with a high Ozone Depletion Potential (ODP) were replaced with HCFC refrigerants with a low ODP, and then HCFC refrigerants were replaced with HFC refrigerants with zero ODP. Together with the adoption of each refrigerant, performance enhancements were promoted (**Figure 1**).[1]

In recent years, however, with the progress of replacement with HFC refrigerants with a high Global Warming Potential (GWP), concerns about the effects of HFC refrigerants on global warming have surfaced. In particular, since the F-gas regulations in Europe and the Fluorocarbons Emission Control Law in Japan took effect, conversion to low GWP refrigerants has been desired of advanced countries.

Centrifugal chillers are widely used not only for heat source equipment used for processing at a factory, but also for general air conditioning such as building air conditioning. The specifications required for centrifugal chillers have gradually changed according to changes in market needs and applications. The installation of an inverter as standard equipment in centrifugal chillers has become prevalent, with which the reduction of energy consumption under year-round operating conditions is expected. With the increase in demand for the replacement of existing equipment, greater importance is being placed on compactness which provides superior installability.

In this paper, the ETI-Z series centrifugal chillers using the HFO-1233zd(E) low GWP refrigerant will be introduced. The series was launched in September 2015 to adapt to the replacement of refrigerants and meet market needs.

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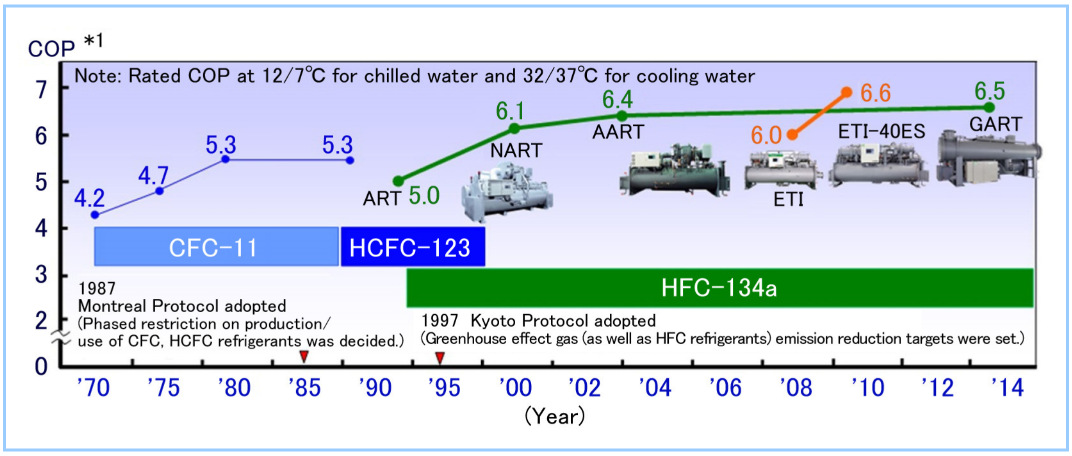

Figure 1 Refrigerants applied to centrifugal chillers and changes in performance*1

*1: COP: Coefficient of performance, the value obtained by dividing the generated cold heat amount by the consumption electrical energy. The larger the COP value, the better the performance.

2. Low GWP refrigerants for centrifugal chillers

In addition to the typical refrigerant characteristics, three criteria in the selection of refrigerants of centrifugal chillers, which have the largest capacity among heat source equipment for refrigeration and air conditioning, are described below.

(1) Basic characteristics of refrigeration cycle efficiency, etc.

An efficient refrigeration cycle and an appropriate working pressure range are required. Since the efficiency of the refrigeration cycle has a significant effect on the performance of the chiller, high efficiency of the refrigeration cycle is needed for the reduction of energy consumption and operational costs as well as indirect CO_2 emissions reduction during operation. For an excessively high working pressure, the walls thickness of the chiller components must be thick to ensure the strength of the components, while for an excessive low working pressure, the sizes of the components of refrigerant gas parts must be large. In either case, the costs increase. Accordingly, an appropriate working pressure range is important.

(2) Availability

Although a significant amount of refrigerant is filled in one centrifugal chiller, the total amount of refrigerant used in the centrifugal chiller is small compared with that of other air conditioning equipment (i.e., household and automotive air conditioning systems, etc.). Therefore, considering the cost reduction of refrigerant through a stable supply and mass production effect, it is important to ensure the total amount of refrigerant used in the centrifugal chiller and other air conditioning equipment and foaming agent.

(3) Safety

With no toxicity and non-combustibility (no fire shall occur in use in machine rooms), being able to handle it safely is required.

As candidates for low GWP refrigerants for centrifugal chillers, the HFO refrigerants shown in **Table 1** have been studied. As refrigerants with relatively similar characteristics to the current refrigerant HFC-134a, HFO-1234yf and HFO-1234ze(E) have been studied and technical studies about the application as a refrigerant for centrifugal chillers have already been conducted.

However, due to the slight combustibility of both refrigerants, which poses a safety issue, as well as domestic laws and regulations and the poor availability for HFC-1234yf, they have yet to actually be adopted.

Therefore, HFO-1233zd(E) refrigerant was selected as the candidate for low GWP refrigerant, because although it has significant differences in physical properties from the current refrigerant HFC-134a, it is superior in terms of basic characteristics such as refrigeration cycle efficiency, and has no availability or safety issues.

Table 1 Comparison between the conventional refrigerant and alternative refrigerant[2, 3]

	Conventional refrigerants			Alternative refrigerants		
	HCFC-123	HFC-245fa	HFC-134a	HFO-1234yf	HFO-1234ze(E)	HFO-1233zd(E)
Global warming potential	79	858	1 300	<1	<1	1
Ozone depletion potential	0.012	0	0	0	0	0
Combustibility	Non-combustible	Non-combustible	Non-combustible	Slightly combustible	Slightly combustible	Non-combustible
Toxicity (allowable concentration) [ppm]	B1(50)	B1(300)	A1(1 000)	A2L(500)	A2L(1 000)	A1(800)
Atmospheric lifetime	1.4 years	7.6 years	13.8 years	10.5 days	16.4 days	26 days
Boiling point (atmospheric pressure) [°C]	27.8	15.1	-26.1	-29.4	-19.0	18.3
Saturated liquid density (25°C) [kg/m^3]	1464	1 339	1 207	1 092	1 163	1 263
Saturated gas density (25°C) [kg/m^3]	5.87	8.55	32.35	37.93	26.3	7.19
Latent heat (25°C) [kJ/kg]	171.4	190.9	177.8	145.4	166.8	190.6
Theoretical COP [−]*2	7.43	7.36	7.16	6.96	7.18	7.39

*2: 2-stage compression 2-stage expansion sub-cooler cycle. Evaporating temperature 6.2°C, condensing temperature 37.7°C, degree of subcooling 4°C, refrigeration cycle COP at adiabatic efficiency 88%

3. Technologies toward efficiency improvement, downsizing and performance enhancement for chillers using low GWP refrigerant

The refrigerant gas density of HFO-1233zd(E) is about one-fifth that of HFC-134a, and the latent heat is equivalent. Therefore, the cross sections of the paths in the sections such as the compressor, evaporator, condenser and gas pipes through which refrigerant gas flows, must be increased. To obtain performance and compactness equivalent to those of existing ones, it is important to realize the downsizing of the chiller and further enhance performance. The technologies for such downsizing and performance enhancements are described below.

3.1 Increase in efficiency and downsizing of compressor

(1) Improvement of aerodynamic design

In pursuit of enhancing performance and downsizing the compressor, the blade shape of the impeller suitable for the physical properties of the target refrigerant was newly designed. Compared with the impellers of conventional chillers, the new impeller was designed with the specifications for a larger gas flow, aiming at downsizing while maintaining high efficiency by increasing the gas flow by about 60% with the same blade size compared with conventional chillers. When the design gas flow of the impeller is increased, the adiabatic efficiency tends to be reduced. Through the application of shape optimization logic in addition to the conventional design methodology for the leading and trailing edge shapes of impeller, blade angle distribution, shape of the flow path at the stationary part, and shape of the inlet guide vane, higher efficiency compared with conventional chillers was achieved. In addition, by using an impeller manufactured by machining a proven high-strength aluminum material, high reproducibility for the design performance was realized.

(2) Direct coupling of compressor and motor

With the existing chiller, the speed of the impeller is increased from the rotation speed of motor via the speed increasing gear. In the developed chiller, utilizing the characteristics of the refrigerant, it has a structure where the impeller is directly coupled to the motor shaft and therefore offers the following advantages:

- Downsizing by increasing the speed of the motor
- Downsizing of the compressor unit and the reduction of loss by omission of the speed increasing gear
- Performance enhancement by the reduction of the number of compressor bearing supports (Existing chiller: 8 rows → Developed chiller: 3 rows)
- Reduction of the amount of lubricant

3.2 Downsizing of heat exchanger

(1) Evaporator, condenser

In the evaporator and the condenser, a shell and tube heat exchanger is adopted, and a high-performance thin-walled heat exchanger tube is adopted. In addition, the combination of the number of heat exchanger tubes, the length of the heat exchanger tubes, the diameter of the heat exchanger tubes and the chilled water or cooling water flow direction is optimized and the heating surface area is minimized. Since the absolute pressure is reduced compared with the existing heat exchanger, the heat exchanger tubes are arranged so that the reduction of the heat exchange performance affected by the liquid column in the evaporator is minimized. Furthermore, the flow rate of the refrigerant gas in the evaporator or the condenser becomes high, and therefore, the pitch and the arrangement of the heat exchanger tubes were determined with consideration given to the prevention of carryover in the evaporator and the reduction of pressure drop at the condenser tube bundle. For the evaporator, the droplet separation structure for the prevention of carryover was improved, thereby achieving a compact size similar to the existing heat exchanger.

(2) Subcooler

In the developed chiller, as in the existing chiller, a subcooler is adopted to help enhance performance. In the conventional chiller, the brazing type plate heat exchanger was adopted as the subcooler, while this chiller adopts a condenser built-in type subcooler with the liquid pool incorporated in the lower part of the condenser, which enables the pressure drop on the refrigerant side in the heat exchanger to be reduced. As is the case with the condenser, the combination of the length, number and diameter of the heat exchanger tubes is optimized and the refrigerant passage structure is designed so that the heat transfer performance can be ensured while the pressure drop on the refrigerant side is reduced.

3.3 Enhanced functions with state-of-the-art microcontroller board

In the developed chiller, a state-of-the-art microcontroller board is adopted to facilitate operation by users and to add high-level functions. The characteristics of the state-of-the-art microcontroller board are as follows:

- The liquid crystal display size is increased from the conventional 10.4-inch to 12.1-inch to improve the viewability. In addition, a resistance film type touch panel is adopted to make the operation methods and procedures easy to understand.
- The processing speed of the core CPU was increased, allowing higher-level and more complicated control and a plurality of high-speed communications.
- The number of languages available was increased from 15 to 30, allowing use in more language regions.
- SDHC cards (up to 32 GB) can be used, so that more operation data records can be stored for more convenient use in troubleshooting during maintenance and in the event of failure.

In addition to the aforementioned improvement of the microcontroller board, the viewability of the operation data display window was increased by modifying the display items and the display positions. In addition, it has the function of supporting the initial measures to be taken in the event of a failure by displaying failure factors and solutions, as well as failure names (**Figure 2**).

Figure 2 Appearance and display window of control panel adopting state-of-the-art microcontroller board

4. Characteristics of the new series of chillers

Through the adoption of the aforementioned technologies, the ETI-Z series, with the refrigerant replaced, achieved higher efficiency and equal compactness compared with existing chillers, even though the refrigerant gas density was significantly reduced to about one-fifth. The characteristics of the new series are summarized below.

4.1 Performance enhancements

In a drive with an inverter equipped as standard with the same capacity as the conventional refrigerant, the COP is 6.1 under the JIS conditions (chilled water inlet 12°C/outlet 7°C, cooling water inlet 32°C/outlet 37°C), while in the ETI-Z series, the maximum COP is 6.3, which exhibited a performance improvement of about 3% (**Table 2**).

Table 2 Comparison of specifications between the developed chiller and the existing chiller

	Existing chiller	Developed chiller
Chiller model	ETI-20	ETI-Z20
Cooling capacity	200USRt (703kW)	200USRt (703kW)
Refrigerant	HFC-134a	HFO-1233zd(E)
Chilled water temperature	12°C in/7°C out	
Chilled water flow rate	121.0m^3/h	121.0m^3/h
Cooling water temperature	32°C in/37°C out	
Cooling water flow rate	140.2m^3/h	139.6m^3/h
Electric power consumption	115.0kW	111.3kW
COP	6.1	6.3
L×W×H	3.7m×1.5m×1.8m	3.8m×1.6m×1.7m
Footprint	5.55	5.83
Delivery weight	3.9ton	4.2ton

The refrigerant HFO-1233zd(E) adopted in the developed chiller is called “low-pressure refrigerant,” and has a small difference between the high and low pressures during operation. When CFC-11 or HCFC-123, which has a refrigerant pressure relatively close to that of HFO-1233zd(E), were adopted as refrigerants, a refrigerant pump for supplying the refrigerant for cooling the motor and the lubricant was used under the operating condition where the cooling water temperature was low. This developed series allows operation without a refrigerant pump for supplying cooling refrigerant even under the condition where the cooling water temperature is low, through consideration given to the arrangement of the components such that the size of the lift head that supplies the cooling refrigerant becomes small, as well as to the cooling passage including the inside of the compressor unit. In addition, it allows operation without driving a refrigerant pump, which provides auxiliary machine power, resulting in the improvement of performance especially at the time of partial loading operation

4.2 Downsizing

In addition to the downsizing of the compressor and the heat exchanger described in Section 3, the compact design was achieved by integrally incorporating the inverter unit in the chiller and arranging the auxiliary machines and small containers under the condenser. Compared with the series in which the conventional refrigerant HFC-134a is used, the footprint for the ETI-Z series is, in spite of the fact that the volume of refrigerant gas is about five times as large as that of the existing series, increased by only about 5%, and the ETI-Z series can be said to have a very compact design. Compared with the conventional chillers to be replaced that were launched more than 15 years ago, it achieved a 35% reduction of the footprint.

4.3 Advantages of adoption of low-pressure refrigerant

The newly adopted refrigerant has a low saturation pressure of less than 0.2MPa(G) at 50°C, and under the general specification conditions of centrifugal chillers, the High Pressure Gas Safety Law in Japan is not applicable. Compared with the conventional refrigerant HFC-134a, it is easier to handle in introduction and maintenance because the submission of a high pressure gas manufacturing license or registration and the appointment of a person responsible for refrigeration and safety, safety education or periodical self-inspection and legally defined inspection are not required.

5. Conclusion

The ETI-Z series is the successor to the ETI series of high-performance and compact centrifugal chillers with a small capacity range developed in response to the needs of the domestic market and the ETI-Z presents a solution to the conversion to low GWP refrigerant, which has become an issue in recent years. The ETI-Z series follows the same characteristics that gained popularity in the existing ETI series, such as an integral inverter equipped as standard, high-performance properties including partial loading and a compact design offering superior installability. Further high performance and high functionality were achieved through the optimum design for the new refrigerant and the adoption of the latest microcontroller board. The refrigerant adopted in the developed chiller is planned to be applied further to the capacity range exceeding 1000USRt, and it is expected to be introduced not only for small capacities in centrifugal chillers, but also for a wide range of capacities.

It is anticipated that the launch of the developed chiller will promote conversion to low GWP refrigerants. To continue to meet customer needs in the future, we are going to promote the development of products demanded by the market.

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